BURGESS

Density and Strength
Of Gravel Concrete

Civil Engineering

B. S.

1908

DENSITY AND STRENGTH OF GRAVEL CONCRETE

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1908

UNIVERSITY OF ILLINOIS

June 1, 190 8

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

BENJAMIN PAYSON BURGESS

ENTITLED DENSITY AND STRENGTH OF GRAVEL CONCRETE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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INTRODUCTION

The laws relating to the grading of sizes in concrete aggregate seem to have received very little attention at the beginning of the scientific study of this branch of engineering construction. Investigators set down only a few hard and fast rules that gave fairly good results, but did not give the best concrete attainable. Within recent years however some very careful and extensive tests have been made for determining the proportions of different sizes of the aggregate to use in order to obtain the densest and strongest concrete.

Two general methods have been used for determining the proportions in concrete; the first, to adjust the proportions so that the voids of the aggregate shall be filled with mortar and the voids of the sand with cement
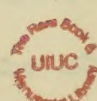
paste; the second, to fix the propor-
tions without any reference to the
voids in the material. It has been
found by experiment that a con-
siderable saving of cement can be
made by the use of more scienti-
fic methods of proportioning
than those stated above. Though
this reduction in the quantity of
cement amounts to a considerable
saving of cost in a large contract,
the saving would not amount
to much in a small job and
the usual methods would be
more practicable.

The best known authentic
and extensive tests on the propor-
tioning of concrete were carried
on at Little Falls, New Jersey, in
1901, and at Jerome Park Reservoir,
New York in 1904, 05, and 06. The
results of these experiments ap-
peared in a paper by Fuller and
Thompson before the American

Society of Civil Engineers in 1907.
The general conclusion arrived at
was, that the densest and strong-
est concrete was obtained when
the mixture of the sizes of the
aggregate gave for its mechan-
ical analysis a curve that ap-
proached a parabola which had
its beginning at the zero of co-
ordinates and passed through
the intersection of the curve of
the coarsest stone with the
100 % line. Several important con-
clusions were drawn from these
experiments.

(1) "Aggregates in which particles
have been specially graded in
sizes so as to give, when water
and cement were added, an ar-
tificial mixture of the greatest
density, produce concrete of great-
er strength than mixtures of ce-
ment and natural materials
in similar proportions. The

average improvement in strength
by artificial grading under the
conditions of the test was about
14 %."

(2) "The strength and density of
concrete is affected by the varia-
tions in the diameters of the par-
ticles of sand more than by
the variations in the diameters
of the stone particles."

(3) "The strength and density of
concrete is affected slightly, if at
all, by decreasing the quantity of
the medium sized stones of the
aggregate and increasing the
quantity of the coarsest stones."

(4) "It follows from the foregoing
conclusions that the correct pro-
portioning of concrete for strength
consists in finding with any
percentage of cement, a concrete
mixture of maximum density,
and increasing or decreasing
the cement by substituting it

for fine particles of sand or vice versa."

(5) In ordinary proportioning with a given sand and gravel and a given percentage of cement, the densest and strongest mixture is attained when the volume of the mixture of sand and cement and water is so small as just to fill the voids of the larger particles. In other words, in practical construction, use as small a proportion of sand and as large a proportion of the larger particles as possible without producing visible voids in the concrete."

(6) The best mixture of cement and aggregate has a mechanical analysis curve resembling a parabola, which is a combination of a curve approaching an ellipse for the sand portions and a tangent straight line for the stone portion. The ellipse runs

to a diameter of one tenth of the
diameter of the maximum size
of stone, and the stone from
this point is uniformly graded."

In the following pages will
be stated the results and methods
of a number of tests made by
the writer. The methods and
tables used in the experiments
described by Fuller and Thomp-
son before the American Society
of Civil Engineers in 1907 were
followed throughout so that a
comparison of results could be
made.

DESCRIPTION

General Method

Density and strength tests
were made with gravel concrete
using 10% of cement in all
cases. Different combinations of
sizes of sand and gravel were

used in order to study the effect
of the grading of the sizes upon
the density and strength of the
concrete. The test for density
was made by measuring the
volume of concrete resulting
from a definite weight of ma-
terials. For testing the compres-
sive and transverse strength
6 inch cubes and 6"x 6"x 6'- 6" beams
were then made up from the
concrete having the same com-
position of dry materials as
used in the density tests.

    Five different sets of tests
were made, so planned that
there should be a wide variation
in the grading of the sizes.
In four cases 2" stone was the
maximum size used and in
the fifth case the maximum
size was 3/4" stone. In all cases
the cement is included in
the mixtures represented by

the mechanical analysis curves on Plate 3.

Mechanical Analysis

Mechanical analysis consists in separating the particles of any dry material used in concrete, into a number of different sizes of which it is composed. The relative amounts of these separated sizes can then be represented by a curve the abscissae of which represent the diameters of the particles and the ordinates at any point the percentage of the total weight smaller than the corresponding diameter.

Cement

Chicago A A portland cement was used throughout the tests. Its strength, fineness, and specific gravity were tested and the results obtained are shown on Table 1.

TABLE 1.

Results of Cement Tests

Fineness Test Parts in 1000			Strength in Pounds per sq. in.			Remarks
Sieve	Amt. Passing	Percent Passing	No.	Test 1.	Test 2	Sp. Gr. of
No. 200	802.00	80.2	1	805	720	Cement=
No. 150	969.00	96.9	2	730	650	3.12
No.100	988.50	98.85	3	775	805	21.75 % of
No. 74	1000.00	100.0	4	790	780	water used.
			5	710	765	7 day test
			Average	762	744	

TABLE 2.

Sizes of Sieves

| Commercial Nos. of sieves	Diameters passing sieves in inches	Commercial Nos. of sieves	Diameters passing sieves in inches
16	.045	74	.0071
20	.034	100	.0058
30	.020	150	.0036
40	.016	200	.0027
60	.0115		

TABLE 3

Specific Gravity of Gravel

| Sizes	Average Sp. Gr.
2"- 1½"	2.80
1½"- ¼"	2.67
¼"- No.16	2.63
No.16- Pan	2.61

Aggregate

The aggregate used was fine
washed gravel from along the
Wabash river. Though it contained
much foreign matter that usually
accompanies commercial gravel,
that part was removed as far as
possible before the experiments
were performed. Owing to the great
lack of large sizes in the aggregate
2 inch and 1½ inch sizes were obtain-
ed from other sources and these
pieces were for the most part ir-
regular pieces of granite.

Screening of Gravel

The gravel was separated into
various sizes by means of square
mesh screens and sieves. A rocking
frame as shown in Plate 1 was
built for screening the nine largest
sizes. This frame was capable of
holding five screens besides the
tight box at the bottom. The gravel
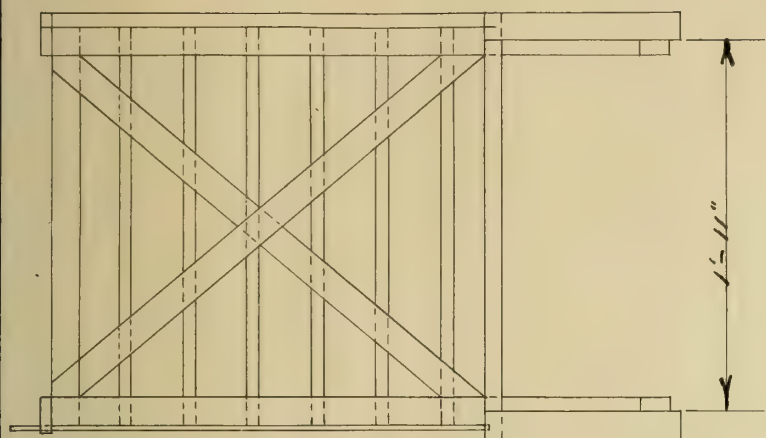
END ELEVATION
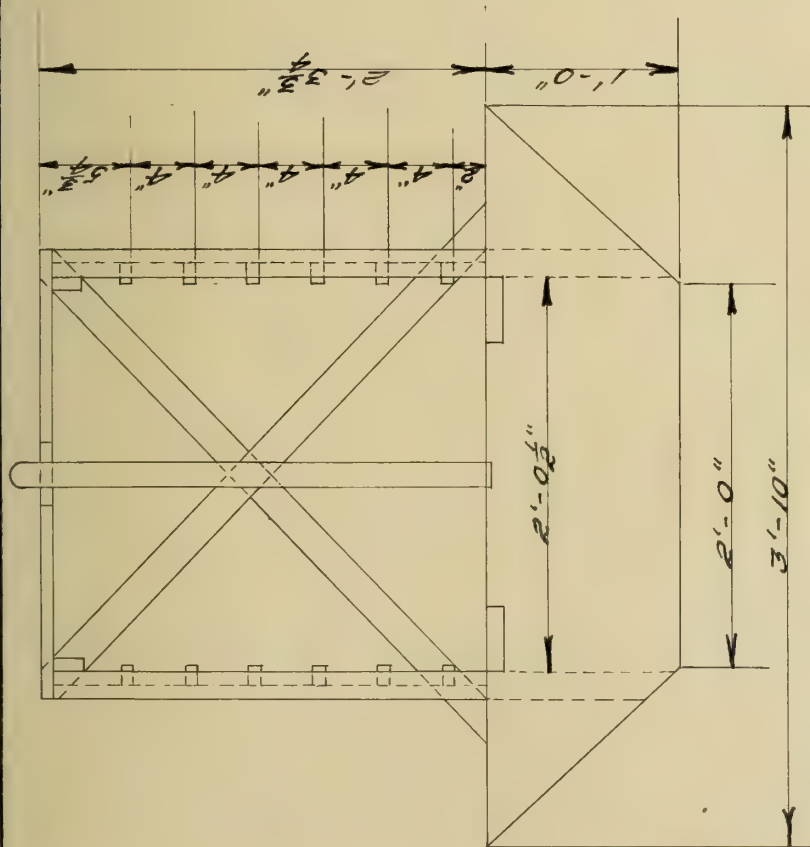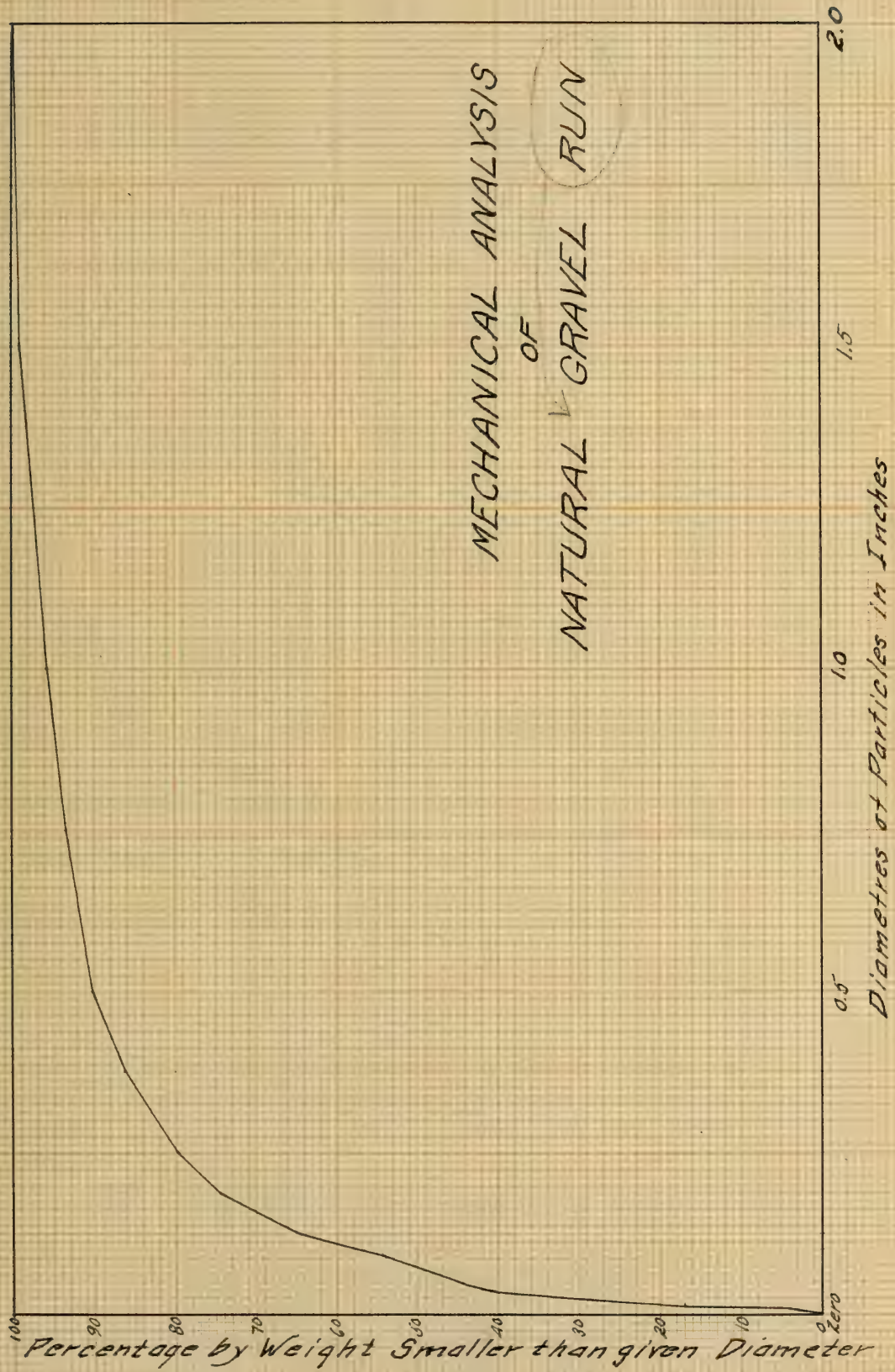
FRONT ELEVATION

ROCKING FRAME

PLATE 1.

Scale 1 in.= 1 ft.

was first shaken in the four largest
screens for 2 minutes. The material
going through all these screens
and remaining in the box at the
bottom was then shaken in the
next five screens for 10 minutes.
The part that then remained in
the box was separated into the
other ten sizes by means of a
Howard and Morse Testing Sieve
Agitator. This machine was run
30 minutes for each charge of 1½ kil-
ograms. A mechanical analysis of
the natural gravel was made as
described above and the results
are shown in Table 2.

Specific Gravity of Gravel

On account of the great differ-
ence in the weight of the different
sizes of the gravel a special me-
thod was devised to obtain the
average specific gravity of the
aggregate used in each mechanical

MECHANICAL ANALYSIS
of
NATURAL ⅴ GRAVEL RUN

Diametres of Particles in Inches

Percentage by Weight Smaller than given Diameter

PLATE 4

analysis. An average was found for
four different sets of sizes, the re-
sults of which are shown in Table 3. p 9.
The amounts of these different
sizes are obtained from the me-
chanical analysis table and by
multiplying the amount by the
different specific gravities and
by dividing by the total amount
the average for each curve was
determined. The difference was
found to be so small for the dif-
ferent curves that the average
specific gravity of 2.65 was used
for all cases.

Curves

The curves are shown in
Plate 3.

Curve No. 1. represents the aver-
age natural run of the gravel used.

Curve No. 2. starts at the vertical
axis at 7% and runs as an ellipse
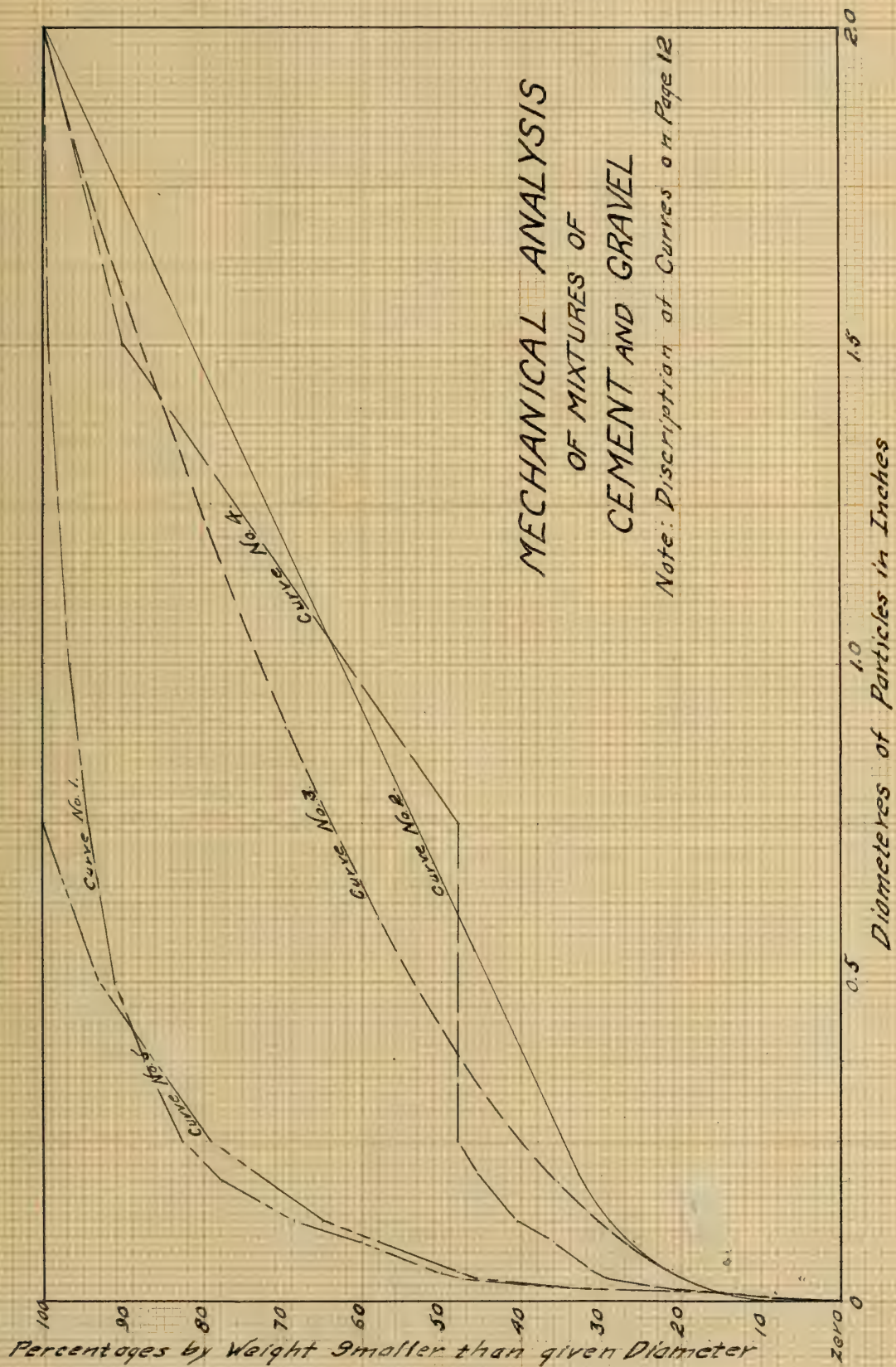to a point corresponding to 0.2 inch

MECHANICAL ANALYSIS
OF MIXTURES OF
CEMENT AND GRAVEL

Note: Discription of Curves on Page 12

Curve No.1.
Curve No.5
Curve No.4
Curve No.3
Curve No.2

Diameteres of Particles in Inches

Percentages by Weight Smaller than given Diameter

PLATE 3

TABLE 4

Table of Percentages
of
Cement and Different Sizes of Aggregate
to
Total Weight of Dry Material

Size of Particles in inches	Percents of Total Weight				
	Curve No.1	Curve No.2	Curve No.3	Curve No.4	Curve No.5
2.00 - 1.50	0.80	18.70	12.40	10.00	0
1.50 - 1.00	2.80	18.70	14.90	28.00	0
1.00 - 0.75	2.10	9.35	8.70	14.00	0
0.75 - 0.50	3.20	9.35	10.60	0	7.00
0.50 - 0.375	3.60	4.68	6.10	0	7.00
0.375 - 0.250	5.80	4.68	7.43	0	7.00
0.250 - 0.1875	4.90	2.34	4.38	2.60	7.00
0.1875 - 0.125	2.10	3.33	5.23	4.80	7.00
0.125 - 0.09375	8.50	5.50	3.13	4.60	7.00
0.09375 - 0.045	10.20	2.36	6.19	5.40	10.00
0.045 - 0.034	2.80	1.72	1.82	1.40	2.60
0.034 - 0.020	11.20	3.78	2.81	6.00	11.20
0.020 - 0.016	9.80	1.01	0.98	5.10	9.40
0.016 - 0.0115	11.10	1.26	1.25	5.90	10.80
0.0115 - 0.0071	1.20	1.53	1.41	0.70	1.20
0.0071 - 0.0058	1.50	0.54	0.32	0.80	1.50
0.0058 - 0.0036	0.50	0	0	0.20	0.50
0.0036 - 0.0027	0.20	0	0	0.10	0.20
0.0027 - Pan	0.70	2.52	2.40	0.40	0.60
Cement	10.00	10.00	10.00	10.00	10.00
Total	100.00	100.00	100.00	100.00	100.00

size. From this point it is a straight
line to the intersection of the ordi-
nate 100% and abscissa 2.0 inch.
The equation of the ellipse was
$(y-7)^2 = \dfrac{b^2}{a^2}(2ax - x^2)$ where $a = .36$ and
$b = 29.0$. This equation and con-
stants a and b were the same
as for the "ideal curve" for gra-
vel concrete in the Jerome Park
tests, since the scope of the exper-
iments here performed was not
sufficient to permit preliminary
tests to be made in order to find
what ellipse would be the best
for the gravel used.

Curve No. 3 starts at the vertical
axis at 7% and runs as a parabola
to the intersection of the ordinate 100%
and abscissa 2.0 inch.

Curve No. 4 & 5 were broken line
curves as shown on Plate 3 so chosen
as to give new combinations of
sizes of sand and gravel. In curve
No. 5, 3/4" stone was the maximum

size used.

Density Tests

Weighing.

All materials were proportioned
by dry weight, the gravel having
been well dried over a steam
drying apparatus before screening.
In each test 20 kilograms of dry
material were used. All weighing
was done on Fairbanks Standard
Scales. These scales weighed to
the nearest 10 grams with a fair
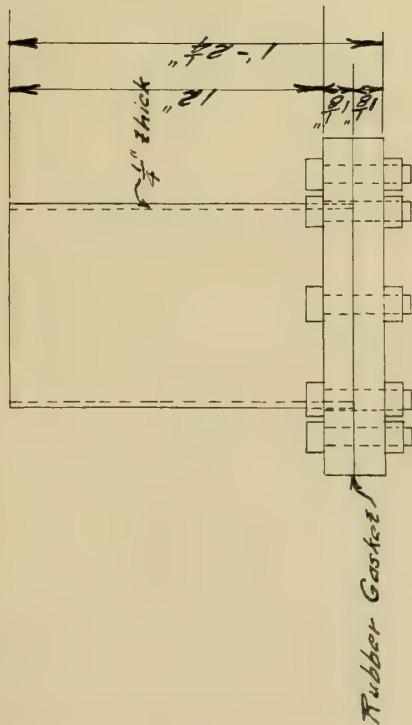degree of accuracy.

Measuring

The volume of the concrete was
measured in an iron cylinder made
of a short piece of wrought iron pipe
as shown on Plate 2. The cylinder
was carefully calibrated, but the re-
sults showed the line of calibra-
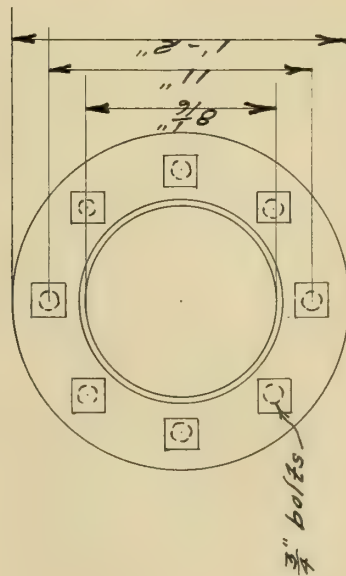tion to be so near a straight line
that the use of the curve was un-

PLATE 2.

CYLINDER
FOR
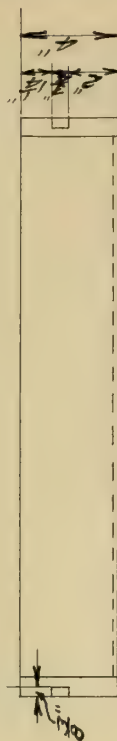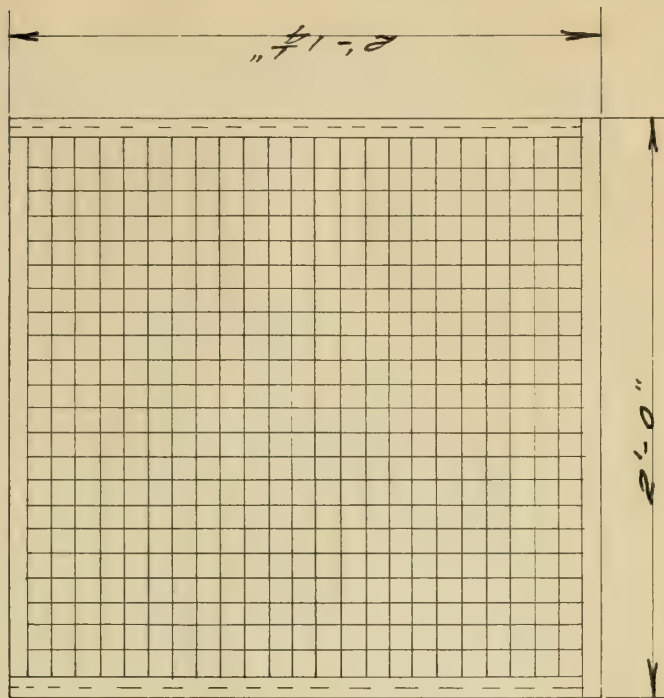DENSITY TEST

SCREEN
FOR
ROCKING FRAME

ELEVATION

PLAN

ELEVATION

PLAN

FIGURE I.
Scale 1½ in.=1ft.

FIGURE II.
Scale 1½ in.=1ft.

necessary.

  The materials were proportioned
by the mechanical analysis curves.
The mixing pan and all appa-
ratus that might become coated
with cement were weighed first.
The aggregate, beginning with
the larger sizes, was then
weighed, the schedule of weights
required having been so arranged
that the different sizes could be
put on top of one another in
the pan, the poise being moved
along the beam for each added
quantity.

Mixing.

  The cement and aggregate were
first mixed dry until a uniform
color was obtained. Water was
then added in sufficient quanti-
ty so that after all was well
mixed the mass was mushy
and would hardly hold its form

in the pan. All mixing was done
with a large trowel. The pail con-
taining the water was weighed
before and after the test and
thus the amount used was de-
termined.

Ramming.

The weight of the cylinder
when empty having been pre-
viously determined the concrete
was put in and well rammed
with an iron rammer. If, after
all the concrete was in the cylinder
and the ramming completed, any
surplus water remained on top,
of the concrete this was removed
by means of a syringe and the
amount thus removed was
weighed so that the water re -
maining in the concrete as set
could be determined.

Final Weighing

The total weight of the cylinder containing the concrete and the weight of the tools having concrete sticking to them were weighed and the results recorded. The material sticking to the pan and tools was assumed to be for the most part cement and sand finer than .0071 of an inch in diameter; therefore this part was taken into consideration in figuring the density. The assumption was made that the fine sand and cement left sticking was in the same proportion as in the total mixture.

Measurement

After the surplus water was removed the top of the concrete was smoothed off as much as possible and the distance from the top of the cylinder to the top

of the concrete was measured, by
means of a steel rule, in several
places around the circumfer-
ence and an average taken. The
total depth of the cylinder being
known the depth of the concrete
was easily computed. The data
and results of the density tests
are shown In Table 5.

Transverse & Compressive Strength
Beams and Cubes

The concrete for the beams
was made by the same general
method that was used for the
density tests. Wooden forms
6"x 6"x 6'-0" were used for the
beams. These forms were made
of 2" lumber and were not design-
ed to keep the water from es-
caping from the bottom. They
were held together by means of
three clamps, one at each end
and the third in the center.

TABLE 5.

Density of Gravel Concrete
With Differently Graded Aggregates

Chicago AA Cement   Wabash River Gravel

No. of Curve	Percentage Cement to total Dry mix.	Max. size stone in inches	Calculated volume of material in one cubic foot of concrete as set in cubic feet				Volume of Voids in 1 cu. ft.
			Cement	Aggregate	Total Dry	Total	
1	10	2.0	.065	.686	.751	.989	.249
2	10	2.0	.073	.775	.858	1.020	.142
3	10	2.0	.077	.812	.889	1.051	.112
4	10	2.0	.072	.775	.847	1.020	.153
5	10	0.75	.066	.700	.766	.974	.234

Iron forms were used for the cubes. These forms were capable of holding three 6" cubes.

The mixed concrete was placed in the forms in 2 inch layers and rammed into place. Care was taken to trowel well along the sides of the forms so as to lessen the chance of large stones arching over and leaving voids along the sides.

Curing

The test specimens were left in the forms for seven days. At the end of that time, after the forms were removed, the cubes were buried in damp sand and the beams were left lying under cover, care being taken to wet them each day until they were tested at the age of 28 days.

Breaking

The cubes were broken by crushing in a Riehle two Screw Testing machine. The upper head of the machine was provided with a ball and socket joint. For three cubes no attempt was made to adjust the bearing surfaces; but in the others these surfaces were faced with plaster of Paris to equalize the pressure. Through a misunder - standing not all the cubes were broken under the same conditions.

The beams were tested in the same machine as the cubes; thirty and sixty inch spans with load applied at center being used. The two halves of the broken beam were used for the short spans. A 6"x 4" plank was used as a rest for the beam so as to cause a more gradual application of the load. The results of the beam and cube tests are shown in Tables 6 & 7.

TABLE 6

Transverse Strength of Gravel Concrete With Differently Graded Aggregates

Reference No.	No. of equation Mech. Analysis Curve	Percentage Cement Dry Materials	Max. size stone in inches	Age in days	No. of Breaks	Transverse Strength in pounds per square inch			
						Maximum	Minimum	Average for Beam	Average for Curve
1	1	10	2.0	28	2	171	171	171	
2	1	10	2.0	28	3	194	179	186	178
3	2	10	2.0	28	3	407	267	316	316
4	3	10	2.0	28	2	354	344	349	349
5	4	10	2.0	28	1	408		408	
6	4	10	2.0	28	3	390	294	345	361
7	5	10	0.75	30	1	113		113	
8	5	10	0.75	30	2	127	83.5	115	114

TABLE 7

Compressive Strength of Gravel Concrete With Differently Graded Aggregates

Reference No.	No. of equation of Mech. Analysis Curve	Percentage Cement Dry Materials	Max. size stone in inches	Age in days	Compressive Strength in pounds per square inch		Bearing Surface
					Maximum Single Cube	Average for curve	
1	1	10	2.0	28	768		Plain
2	1	10	2.0	28	756	762	''
3	2	10	2.0	28	2160		Plaster Paris
4	2	10	2.0	28	2260	2210	'' ''
5	3	10	2.0	28	2834		Plain
6	3	10	2.0	28	2660		Plaster Paris
7	3	10	2.0	28	2850	2781	'' ''
8	4	10	2.0	28	2120		'' ''
9	4	10	2.0	28	2300	2210	'' ''
10	5	10	0.75	28	410		'' ''
11	5	10	0.75	28	480	445	'' ''

CONCLUSION

The following conclusions, drawn by Fuller and Thompson, as quoted in the first part of this article, were verified by the results obtained:-

(1) That the densest concrete is the strongest.

(2) That the substitution of coarser stone for medium sized stone had little effect, if any, on the density and strength.

(3) That a large amount of sand greatly reduced the strength and density.

The ellipse and tangent curve did not appear to be the ideal one for the materials used from the results obtained since the parabola gave denser and stronger concrete. The conclusion drawn from this is that more fine material was necessary to give the ideal curve for the

gravel used than this ellipse
curve gave. This conclusion is
not definitely proved since so
few tests were made and the
amount of error that was apt
to come in on account of the
inexperience of the performer
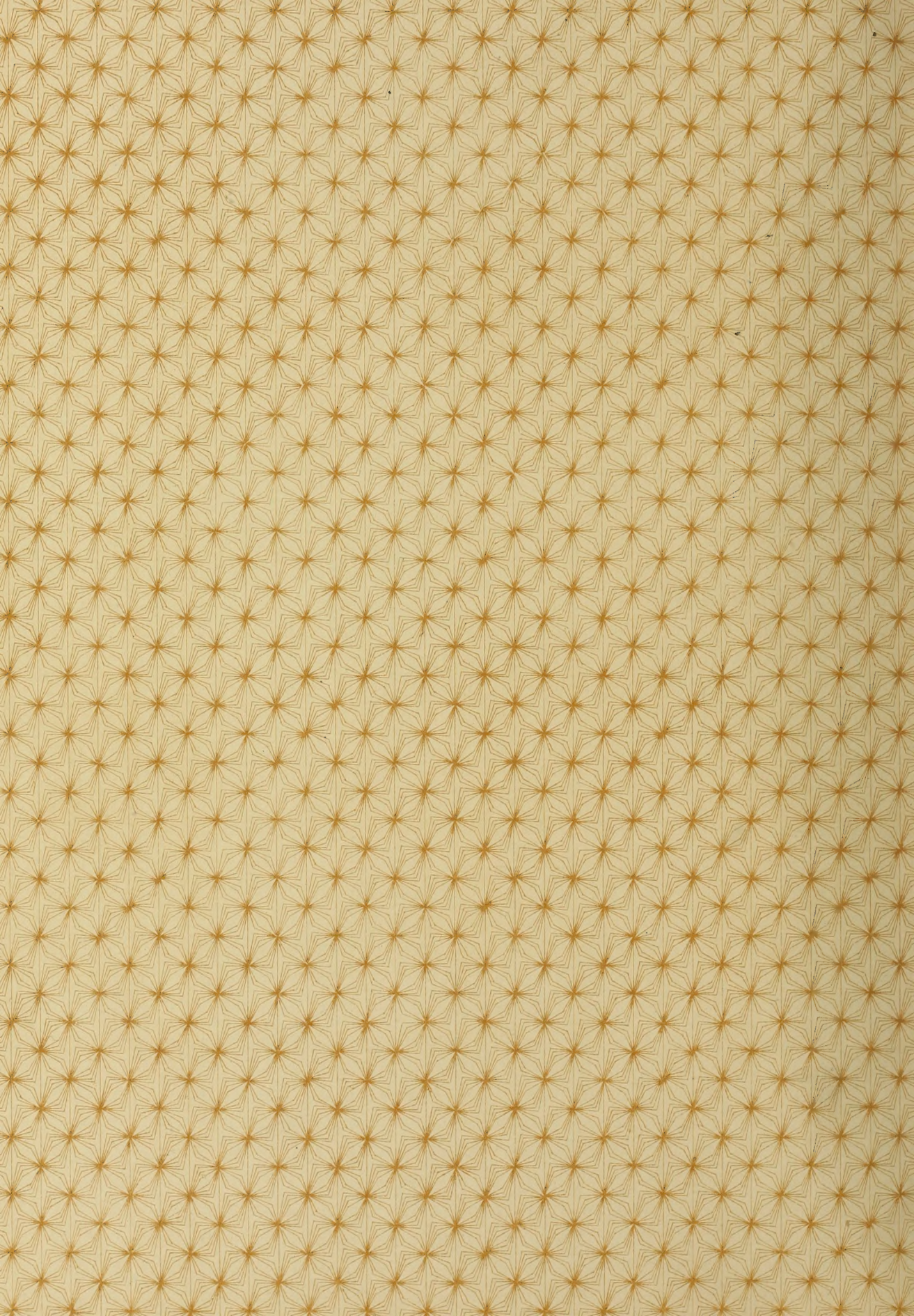made positive proof impossible.

In a continuation of this work
it would be advisable to use cubes
altogether instead of cubes and
beams. The reason for this is
that cubes being smaller a
great many more could be
made with the material used
in the beams and although
the breaking results might be
a little more variable because
a difference of bearing surfaces
gives large variations the greater
number would more than off-
set this objection. A 6 inch cube
is not large enough to make
a test for concrete with stone

2 inches in diameter because with a small sized cube there is too much chance for the stones to arch and leave voids.

On account of the great comparitive amount of the size that would go through a No. 200 sieve that was needed, the time and money spent in sifting this size material was excessive. This difficulty could be easily removed by using 12% of cement instead of 10% because the cement could be substituted for the small sizes in the sand.

On account of the small capacity of the apparatus used for sifting out the small sizes of aggregate a great deal of time was needed to obtain the amount of these sizes necessary. About 42 hours of continual sifting is taken to obtain 1 kilogram of the size

that goes through a No. 200 sieve. For this reason it is seen that in order to get the work completed as expeditiously as possible the material ought to be sifted a long time before the tests are to be made.